RELIABILITY ISSUES AND COST STRUCTURE IN THE 13000 SHS RURAL ELECTRIFICATION PROGRAMME IN MOROCCO

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Abstract

Operation and maintenance (O&M) cost of solar home systems (SHS) in photovoltaic rural electrification (PVRE) programmes is a key factor in the economic viability and long term sustainability. This paper reports on a 13000 installed SHSs programme carried out in Morocco. It is presented the reliability analysis of the SHSs as well as the distribution of real costs of installation, O&M and management to obtain respectively the reliability functions of the SHS components and to characterize the overall programme cost structure.

Introduction

After more than 3 decades of PV applications in rural electrification programmes[1], technical performance, quality and optimal sizing methods have been successfully developed to turn the decentralized solar electrification in a real cost effective solution. Nevertheless, long term sustainability of the SHSs operation is not guaranteed nowadays[2]. On the one hand, the "decentralized nature" of this kind of programmes hinders the forecasting of costs of the O&M actions. On the other hand, the lack of knowledge about SHSs reliability affects directly to the cost forecast uncertainty, as well as the quality of the system operation. The negative impact of these troubles falls mainly on the final users but also on the financial balances of the energy companies charged of the O&M work.

This paper addresses this challenge through the study of the real O&M costs and the reliability of the SHS coming from a large PVRE programme achieved in Morocco.
The programme, known as PERG[3] (*Programme d'Electrification Rurale Global*), has been achieved by several fee for service concessions awarded to private companies.

One of these concessions has reached more than 13000 SHSs installed during 3 years in a vast area of 200000 km^2, which must operate for a 10 years period. The study has been achieved from the real operation data recorded over 5 years by the ESCO (more than 80000 maintenance inputs[4] and the whole accounting).

The results do not pretend to be extended to other experiences because of each PV programme has its own features, but they can be useful to understand some of the weakness points of the PV decentralized rural electrification sustainability.

Reliability of SHS

The reliability analysis has been done considering the failures of more than 13000 installed SHS devices, occurred over a long operating period of 5 years. After the previous arrangement of the maintenance database, the SHS life operating features have been determined looking for the best fit failures distribution of the different components (PV module, battery, charge controller and lamps). The results are shown in Table 1.

Table 1: Reliability figures results of the SHS components

Parameter			BATTERY	CHARGE CONTROLLER	7W LAMP	11W LAMP
Reliability	Normal	θ (years)	5.46	-	-	-
		σ (years)	2.27	-	-	-
	Exponential	λ (% / year)	-	3.67	5.96	5.97
		γ (year)	-	0	-0.294	-0.288
MTTF (years). 95% confidence bounds			5.5 ± 3.4%	27.2 ± 9.5%	16.5 ± 4.0%	16.5 ± 7.0%

The obtained reliability parameters indicate that both, charge controller and lamps, follow an exponential failure distribution, characteristic of electronic devices. Their failure rate will be constant in the time. However, the battery failures, affected mainly by aging factors, fit a normal distribution and its failure rate will be variable. Note that battery has a very low mean time to failure (MTTF) rate compared with the other devices.

The low cases of PV module failures recorded in the maintenance database has not allowed us to apply the same reliability analysis, so a field characterization has been achieved in order to determine the degradation rate of the PV modules.

The PV field-testing has been carried out over a sample of 41 SHSs from different provinces of Morocco after 6 years of operation. The current-voltage (I-V) characteristic curve of each module has been measured under real operating conditions[5], after what has been extrapolated to STC[6]. The maximum STC power (P_M*) obtained from the in-field testing have been compared with the data flash reported by the manufacturer. The test shows a reduction of P_M* of 6.7% on average, and σ = 2.05% as standard deviation.

From these results a reliability model is proposed considering that PV module reach the end of its lifetime when the STC power is below 80% of initial (most of PV manufacturers give warranty conditions ensuring 80% of nominal power of the module after 25 years of operation). The distribution of lifetime periods of the sample is fitted as a Normal distribution in Figure 1.

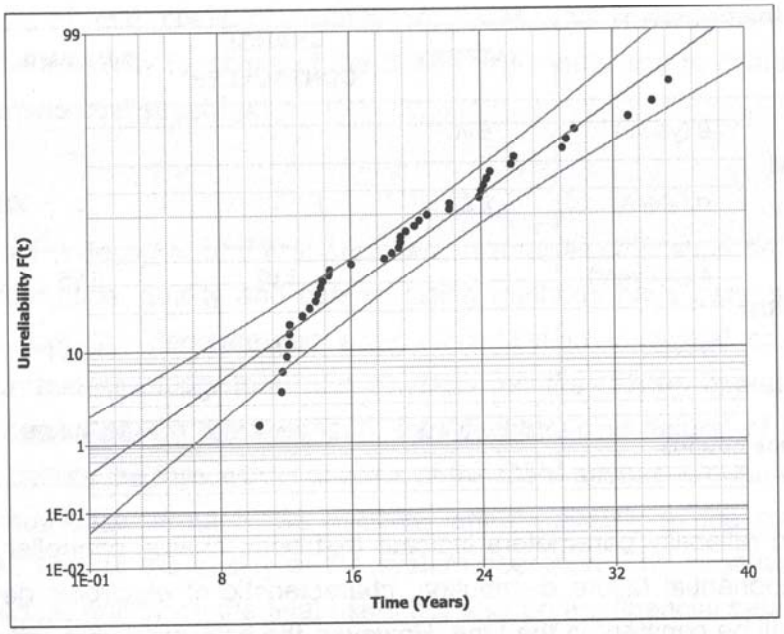

Figure 1: Normal distribution fit for lifetime PV modules taken from the sample of 41 modules, considering failure when they reach the 80% of their initial nominal power

From this fit distribution we have obtained a MTTF = 20.4 years ± 11.4% at 95% of confidence bounds.

Operational cost structure

Based on the operational costs data extracted from the first 5 years, the programme has been analyzed to take out the most relevant costs involved in the O&M phase as well as the comparative appraisal between the 3 main activities: installation, O&M and management[7] (see Figure 2).

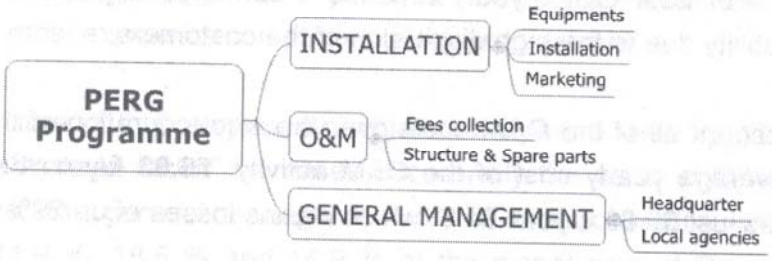

Figure 2: PV rural electrification programme main activities

The cost analysis extended to the 10 years of O&M period shows that the programme will have a global cost of **21 €/Wp**, (**1,574 €/SHS**, referred to the whole installed systems). Figure 3 shows the general cost structure of the programme.

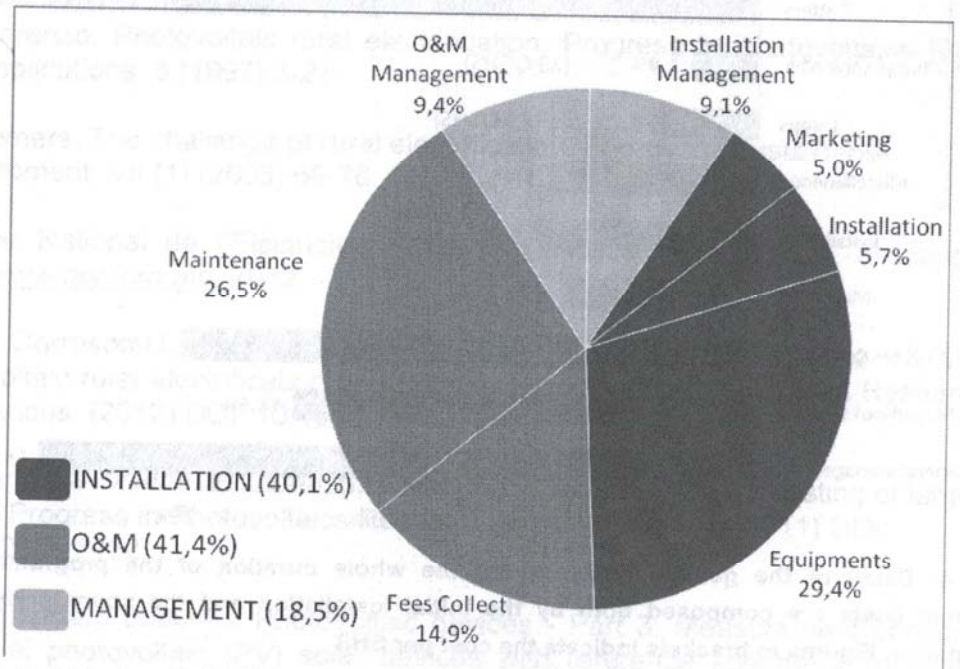

Figure 3: Global cost distribution of the PERG programme for 13449 SHSs and 1.008 MWp installed (considering 75 Wp/SHS)

Note that the installation phase took place from 2006 to 2008 and the price of PV modules were around 3.5 €/Wp, much higher than nowadays market prices.

Maintenance, which includes both spare parts and the maintenance structure, represents **26.5%** of the global programme cost, and it can be expressed as an annual **9.01%** of the equipment investment (41.7 €/SHS·year).

Fees collection activity justifies its weight on the overall programme cost (14.9% of the total cost – or 23.4 €/SHS·year) because it demands a great effort in human capital and mobility due to the high dispersion of the customers.

Taking into account all of the O&M costs over the whole duration of the project, we can get the average yearly cost of the O&M activity: **76.03 €/year·SHS,** being the yearly user fees just **59.09 €/year·SHS,** which means losses of up 29% for the ESCO balance.

Figure 4 shows the incidence of the main costs within the overall programme cost.

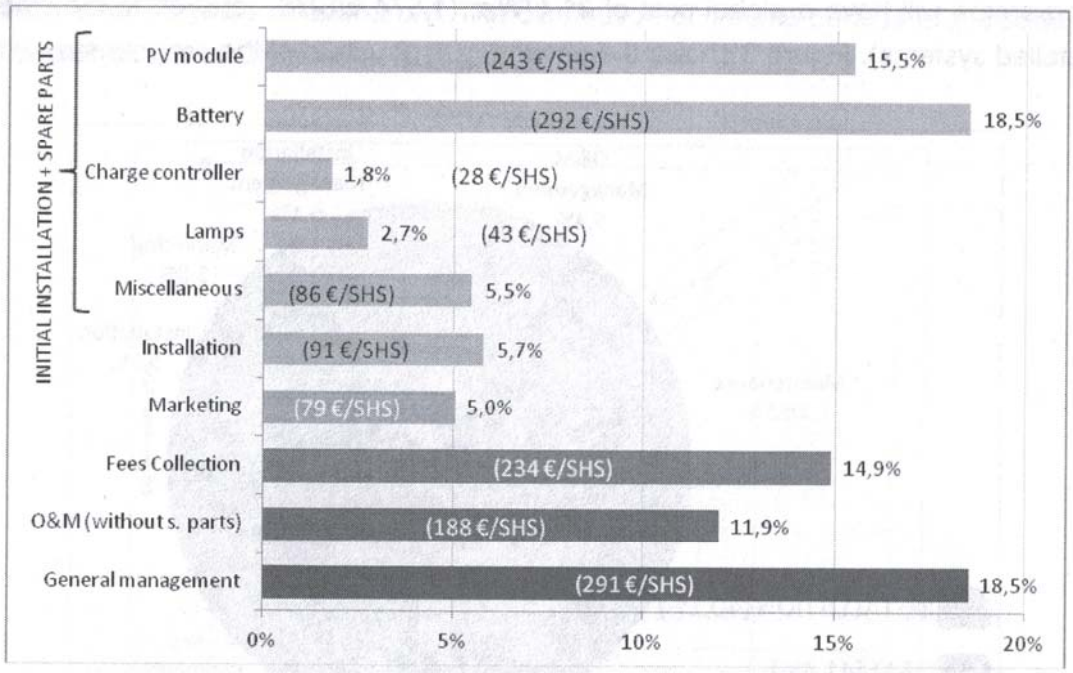

Figure 4: Detail of the general costs during the whole duration of the programme. The equipment costs are composed both by the initial installation and the spare parts of the maintenance. Figures in brackets indicate the cost per SHS

Note that PV module represent just 15.5 % of the overall cost, while battery and general management are 18.5 % respectively, fees collection 14.9 % and O&M (without spare parts) 11.9 %. The relevance of the general management activity high cost is due mainly to the "decentralized nature" of the programme, and also to the lack of potential customers previously forecasted.

Conclusions

A fee for service concession of the Moroccan PERG programme with more than 13000 SHSs has been analyzed from the point of view of the SHSs reliability and the overall programme cost structure. The results indicate a poor reliability index for battery ($MTTF_{battery}$ = 5.5 years) when compared with the other devices ($MTTF_{lamps}$ = 16.5 years; $MTTF_{charge\ controller}$ = 27.2 years; $MTTF_{PVmodules}$ = 20.4 years). Battery will represent the most expensive component of the programme.

The cost structure of this programme, which O&M period lasts for 10 years, shows that the "decentralized factor" increases excessively the costs of O&M, such as the O&M structure, the general management or the fees collection, which represent respectively 11.9 %, 18.5 % and 14.9 % of the global cost of the programme. As many other programmes before, there is an imbalance between the incomes (59.09 €/year·SHS) and the O&M cost (76.03 €/year·SHS), which has negative impact on the ESCO financial balance.

References

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